Title

Baseline vegetation contamination at safety test sites on the NTS and Tonopah Test Range. Describes concentrations of transuranics on/in native vegetation sampled on NTS and TTR in 1990 and 1991, and compares with data gathered in 1970s.

Author

EG&G/EM

101566

Document Date

3/30/93

ERC Index number

05.09.610

Document Type

Report

Box Number

1666-1

Recipients

DOE

Kent Site

EG&G Energy Measurements
Environmental Sciences Department

BASELINE VEGETATION CONTAMINATION AT SAFETY TEST SITES ON THE NEVADA TEST SITE AND TONOPAH TEST RANGE

Summary Report

March 1993

1.0 INTRODUCTION

During the late 1950's and early 1960's, a series of safety tests were conducted at the Nevada Test Site (NTS) and Tonopah Test Range (TTR) to determine the effects of accidental detonation or destruction of a nuclear device. The device was destroyed by chemical explosives which caused little nuclear yield, but the explosion dispersed plutonium (Pu) over large areas at the detonation sites. Contamination is primarily in the upper 2 to 10 cm of the soil surface and on vegetation.

The Comprehensive Environmental Response Compensation and Liability Act (CERCLA) and the Superfund Amendment and Reauthorization Act (SARA) require remediation of these safety test sites. SARA provides for specific procedures for various stages of decontamination of these sites including preliminary assessment, characterization, remediation and certification for delisting. Presently, remediation investigations and feasibility studies are being conducted.

Approximately 800 ha are contaminated with Pu as a result of the safety tests. For large scale Pu decontamination to occur, approximately 280,000 cubic meters of soil must be removed from these sites. Existing vegetation at these sites is also contaminated. Many of the soil decontamination technologies will leave the soil devoid of organic matter and nutrients. If vegetation were removed first and decontaminated separately, the possibility exists to return the cleaned vegetation to the soil. Vegetation in some zones of contamination may have Pu levels below acceptable limits for decontamination, and therefore can be used as transplants or for mulch. The ability to salvage vegetation on these sites will aid in replenishing organic matter and nutrients to the decontaminated soil, thus reducing site-wide reclamation costs.

Previous studies conducted during the early 1970's at these safety test sites by the Nevada Applied Ecology Group (NAEG) indicated that contamination of vegetation was the result of particle resuspension during wind movement and subsequent superficial attachment of contaminated particles to plant foliage (Romney et al. 1975). Contaminated particles, usually less than 44 microns in size, are trapped by hairs and crevices on plant leaves and branches. Contamination of plants by uptake of radioactive

particles by roots was found to be much less than that caused from superficial

Area 13 sites. The vegetation at both of these sites is representative of Mojave-Great Basin Transition Desert. Vegetation at the Tonopah Test Range is representative of the Great Basin desert. Vegetation contamination data collected by NAEG at the TTR was limited in the number of species sampled and may not be sufficient to understand seasonal differences in contamination at these sites.

NAEG researchers examined several native plant species at the Area 5 GMX safety test site to determine the seasonal differences in contamination of leaves (Romney et al. 1975). They noted slight seasonal changes in superficial contamination of plants at the site. Leaf samples collected during the growing season indicated that during leaf development, contamination was lowest at bud-break and a rapid buildup of superficial contamination occurred within 60 days after leaves emerged. After 60 days, contamination levels remained relatively stable. It is not known whether seasonal variations in contamination exist at the other safety test sites.

Because the amount of leaf area within plant canopies can vary seasonally due to moisture conditions, daylength, and temperature, the determination of seasonal variability in plant contamination of the dominant species at these sites may aid in the development of strategies for vegetation removal. For example, if the majority of the dominant species have bud-break at approximately the same time during the spring, then site-wide vegetation contamination may be lower than at other times of the year, and vegetation could be removed at this time.

EG&G/EM Environmental Sciences Department initiated a study in 1990 to characterize the extent of vegetation contamination of at Area 11 (Site D) of the NTS and Clean Slate 2 of the TTR. This study will aid in the development of strategies for vegetation removal or decontamination. Specific objectives of the study were as follows: 1) to determine the level of vegetation contamination across differing zones of soil contamination (i.e. ground zero and outward); 2) to determine if differences in amounts of contamination varied among species within each site; 3) to determine if seasonal variation in contamination existed for dominant species at these NTS and TTR sites; and 4) to determine the interactions of each of the above characteristics. A secondary objective was to compare vegetation contamination results with that of the NAEG to determine if levels of contamination have changed over time.

Vegetation samples were also collected in Area 13 and Double Track of the Nellis Air Force Range. Sample were collected only once with the objective of using these to compare to the other safety test sites and to compare with past NAEG vegetation contamination data.

2.0 MATERIALS AND METHODS

Vegetation samples were collected by removing aboveground plant material from the dominant species. A species mix sample was collected by randomly sampling species and mixing the material together. Vegetation samples were collected at each site within each contamination zone. The zones of contamination used were the same as those designated by Gilbert et al. 1975 in Report NV0-153. This report documents the locations, areal extent and contamination levels for soil Pu contamination at each of the

samples in order to determine the Pu:Am ratios for calculation of Pu load on aboveground plant material.

The experimental design implemented for this study was a split-plot model with zone of contamination and species being the whole plot variables and date of collection being the subplot variable. Significance of variables and interactions was determined using the SAS GLM procedure with an $\alpha=0.05$ level of significance (SAS 1989). Mean separations were conducted using Fisher's Least Significant Difference (LSD) using appropriate error terms produced by split-plot analysis of variance.

3.0 RESULTS AND DISCUSSION

The interactions of zone of contamination, plant species or mix and collection date were examined to determine if spatial and temporal differences exist in vegetation contamination at the Area 11 and Clean Slate sites. The three-way interaction between these variables is of major concern in this study, but can be difficult to interpret because of its complexity (Snedecor and Cochran 1980). To interpret the interaction correctly, gamma Am 241 means must be examined separately for: 1) each contamination zone for each plant species and date of collection; 2) each plant species within each contamination zone and date of collection; and 3) each collection date for each species and contamination zone. Graphs representing each of the above sets of means are presented and interpreted. Results of the statistical analysis of the means in question are also presented to show variability in vegetation contamination for each level of these factors.

3.1 Area 11 Vegetation Contamination

The analysis of variance model for the Area 11 vegetation contamination data indicated significant main effects ($p<0.05$) for the species/species mix and zone of contamination variables. The date of collection variable was not significant. The interactions between zone of contamination and species, and between zone of contamination and date of collection were significant. Although the three way interaction of zone of contamination, plant species and date of collection was not significant at the $\alpha=0.05$ level, mean comparisons for this interaction were conducted because of the highly significant main effects for zone of contamination and the species/species mix variables (Snedecor and Cochran, 1980).

3.1.1 Zone of Contamination Influences.

The interaction of zone of contamination, species or mix, and date of collection was not significant for any zone except Zone 5. With the exception of *E. nevadensis*, vegetation contamination was significantly greater in Zone 5 for all species and the species mix for all dates of collection (Figure 2). Zone 5 levels of contamination were generally three to five times higher than that of other zones sampled regardless of period of collection.

3.1.3 Seasonal Influences.

For all species, contamination across time did not significantly differ within Zones 1, 2, 3, and 4 (Figure 6). Within Zone 5, significant differences among dates of collection existed within each species and the species mix. However, dates when vegetation contamination levels were the greatest were not the same among species. For example, *A. confertifolia* had significantly higher gamma Am 241 levels during January 1991, whereas *C. viscidiflorus* had significantly greater contamination during October 1990. This again illustrates that phenological differences of each species affects the variability in contamination levels over time. The greater contamination exhibited during January by *A. confertifolia* may be the result of lack of leaf turnover prior to the flush of new leaves in the spring and that leaves present had been exposed to contamination for a greater length of time. *C. viscidiflorus* generally flowers during August through October and sticky exudates are secreted by its flowers. This could lead to greater entrapment of contaminated particles by this species.

Contamination levels averaged across species for each date of collection within the separate zones were not significant in Zones 1, 2, 3, and 4 (Figure 7). However, in Zone 5, contamination levels show a gradual trend of increased contamination from the beginning of the sampling in July 1990 until the January 1991 sampling. After the January sampling, contamination levels significantly dropped; this may be an indication of new vegetative growth in May that had yet to be contaminated by resuspension.

3.2 Clean Slate 2 Vegetation Contamination

As with the Area 11 vegetation contamination data, the analysis of variance model for the Clean Slate 2 vegetation contamination data indicated significant main effects ($p < 0.05$) for the zone of contamination and species variables. The date of collection variable was not significant. The two-way interactions between zone of contamination and species, and between zone of contamination and date of collection were significant. Although the three-way interaction between zone of contamination, species and date of collection interaction was not significant at the $\alpha = 0.05$ level, mean comparisons for this three-way interaction were conducted because of highly significant main effects for the zone of contamination and species variables (Snedecor and Cochran, 1980).

3.2.1 Zone of Contamination Influences.

Zone of contamination means for each of the species and species mix exhibited a consistent patterns across dates of collection (Figure 8). Zone 4 samples had higher

Gilbert et al. 1974 reported relatively equal amounts of soil contamination in zones 3 and 4 (6.2 ± 2.5 and 5.4 ± 1.4, respectively) and significantly lower amounts in zones 1 and 2 (0.09 ± 0.03 and 1.8 ± 0.74).

3.2.2 Species Influences.

Mean contamination levels differed among species and the species mix within zones 3 and 4 for each sampling period (Figure 9). The species and the species mix in Zones 1 and 2 were generally not significantly different from each other for each date of

indicating that phenological patterns across species were probably not a significant influence on vegetation contamination.

3.3 Comparison of Contaminated Sites

A comparison of contamination at the various sites will aid in the development of strategies for handling vegetation during site decontamination. If the sites have comparable vegetation contamination, then a comprehensive plan could be written for vegetation handling and use during site decontamination. If the sites do not have comparable levels, then site-specific plans should be developed to address these aspects for site decontamination.

Contamination levels of *A. confertifolia*, a species common to both the Area 11 and Clean Slate sites, were approximately 25 times greater in the ground zero zone (Zone 5) at Area 11 (Site D) when compared to the same zone at Clean Slate 2 (Figure 12A). Levels of contamination for this species in all zones of Clean Slate 2 were comparable to Zones 1, 2 and 3 of site D in Area 11.

Since inconsistent patterns of contamination were observed across sampling dates among species, the mixed species sample may be best for assessing average contamination within zones at each of these sites. During sampling of vegetation at Area 13 and Double Track, mixed vegetation was collected to compare to other safety test sites. Because Area 13 and Double Track were sampled only once, statistical comparisons of the mean contamination values for other site and dates cannot be made because of the unbalanced nature of the data. Figure 12B illustrates mixed vegetation means for zone for Area 11 (Site D), Clean Slate 2, Area 13, and Double Track. Standard errors of the mean for each zone are given to show within-zone variability and

Comparisons of the ground zero zones for each of sites show that Site D in Area 11 had the greatest Pu contamination. This site had five to ten times more Pu in mixed species samples than did the other sites sampled. Zone 4 at the Area 11 site was

in this study, past contamination levels for the NAEG data at the various sites were calculated by using a weighted mean and standard error (i.e., a species having a greater number of individual samples would be weighted greater in the overall mean than a species having a low number of individual samples) of the individual species contamination means and standard errors found in Romney et al. 1975, Table 1, to reflect a mixed vegetation sample for each contamination zone. Statistical mean separation procedures cannot be used to statistically separate the NAEG weighted means for mixed vegetation from this studies' mixed vegetation means due to differences in statistical designs between the two studies and the unbalanced nature of the data, but they do provide a reference for comparison of these sites.

Contamination of Pu in soils at Area 11, Site D appears not to have changed over time (Figure 3). Although soils show higher contamination in some zones and lower contamination in others from 1974 to 1991, the variability in these means indicate they are probably not different. Past and present vegetation contamination at Area 11, Site D had similar patterns and variability, indicating that probably no significant change in vegetation contamination has occurred in 25 years (Figure 13A).

Vegetation contamination at the other sites sampled showed little differences over time. At Clean Slate 2, mean values for this study were somewhat higher in Zones 3 and 4 when compared to the 1974 means, but the variability in each of these means indicate that they are probably not different (Figure 13B). Area 13 mean contamination in Zone 6 (ground zero) was greater in 1974 than in 1991 (Figure 14A). Since dates of collection were not given for the 1974 study, this difference may be the result of seasonal differences or may be the result of spatial differences in sampling. Contamination within zones at Double Track also did not change significantly over time (Figure 14B). These comparisons indicate that in the past 25 years, no large increases or decreases in vegetation contamination within zones at these sites has occurred.

4.0 CONCLUSIONS

1. Variations in vegetation contamination occur over time and are inconsistent among species. At no time of the year do all species exhibit consistently high or low contamination and no single species can be used as and indicator of vegetation contamination. The differences in species contamination over time are probably the result of phenological, architectural, and leaf longevity differences among the plant species. Samples containing a mixture of species may be the best method for assessing average levels of vegetation contamination within zones at each site.

2. Vegetation contamination levels differed across designated zones of soil contamination. Vegetation contamination levels were greatest near ground zero at all sites. Generally, zones the greatest distance away from ground zero had similar contamination. Vegetation in these outer zones could be treated the same during decontamination of the sites.

3. Zone 5 in Area 11 (Site D) had the greatest vegetation contamination level of all sites sampled.

4. Comparisons of vegetation contamination data collected during the early 1970's with that for this study indicate that contamination levels have not changed substantially over the last 25 years.

5. Results of these analyses can be used to help formulate vegetation removal, cleaning, and reuse strategies during decontamination and revegetation phases at the safety test sites on the NTS and TTR. Minimum acceptable levels of vegetation contamination have yet to be identified for these sites. Once the levels have been set, site-specific strategies can be developed using this data as a guideline on how vegetation can be removed, cleaned or reused during decontamination of these sites.

5.0 LITERATURE CITED

Gilbert, R.O., L.L. Eberhardt, E.B. Fowler, E.M. Romney, E.H. Essington, and J.E. Kinnear. 1975. Statistical analysis of plutonium 239-240 and americium 241 contamination of soil and vegetation on NAEG study sites. In: M.G. White and P.B. Dunway (eds.) The Radioecology of Plutonium and Other Transuranics in Desert Environments. U.S. Energy Research and Development Admin. Report NVO-153. pp. 339-448.

Major W.J., K.D. Lee, R.A. Wessman, and R. Melard. 1974. Determination of 239-Pu and 241-Am in large NAEG Vegetation samples. In: P.B. Dunway and M.G. White (eds.) The Dynamics of Plutonium in Desert Environments. U. S. Atomic Energy Comm. Report NVO-142. pp. 107-118.

Romney, E.M, R.G. Lindberg, H.A. Hawthorne, B.G. Bystrom, and K.H. Larson. 1963. Contamination of plant foliage with radioactive fallout. Ecology. 44:343-349.

Romney, E.M., A. Wallace, R.O. Gilbert, and J.E. Kinnear. 1975. 239-240 Pu and 241 Am contamination of vegetation in aged plutonium fallout areas. In: M.G. White and P.B. Dunway (eds.) The Radioecology of Plutonium and Other Transuranics in Desert Environments. U.S. Energy Research and Development Admin. Report NVO-153. pp. 43-87.

SAS. 1989. SAS Users Guide: Statistics SAS Institute. Cary, North Carolina. 953 pp.

Snedecor G.W, and W.G. Cochran. 1980. Statistical Methods. Iowa State University Press. Ames Iowa. 507 pp.

Vines, R.A. 1986. Trees, Shrubs and Woody Vines of the Southwest. University of Texas Press. Austin, Texas. 1104 pp.

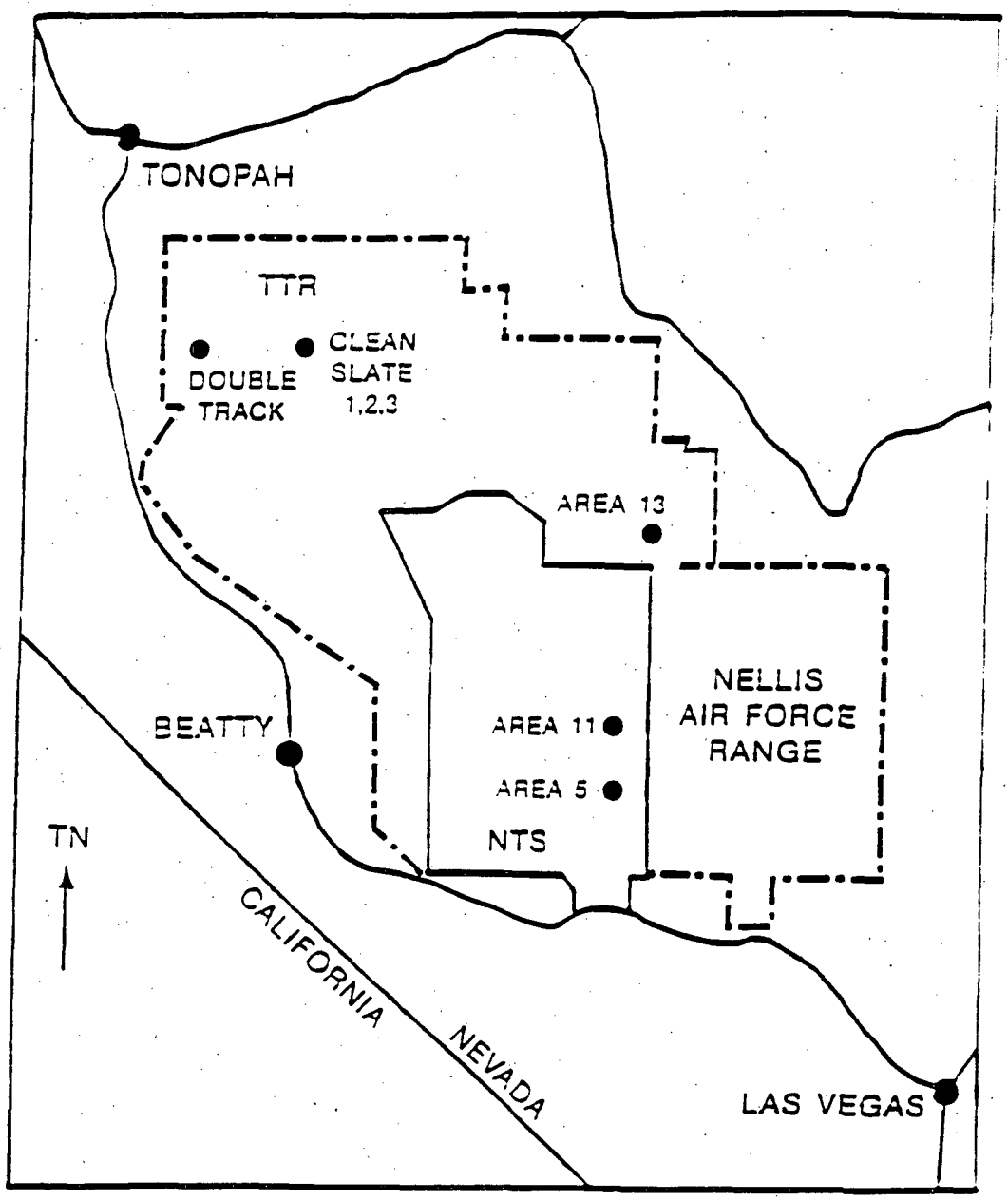
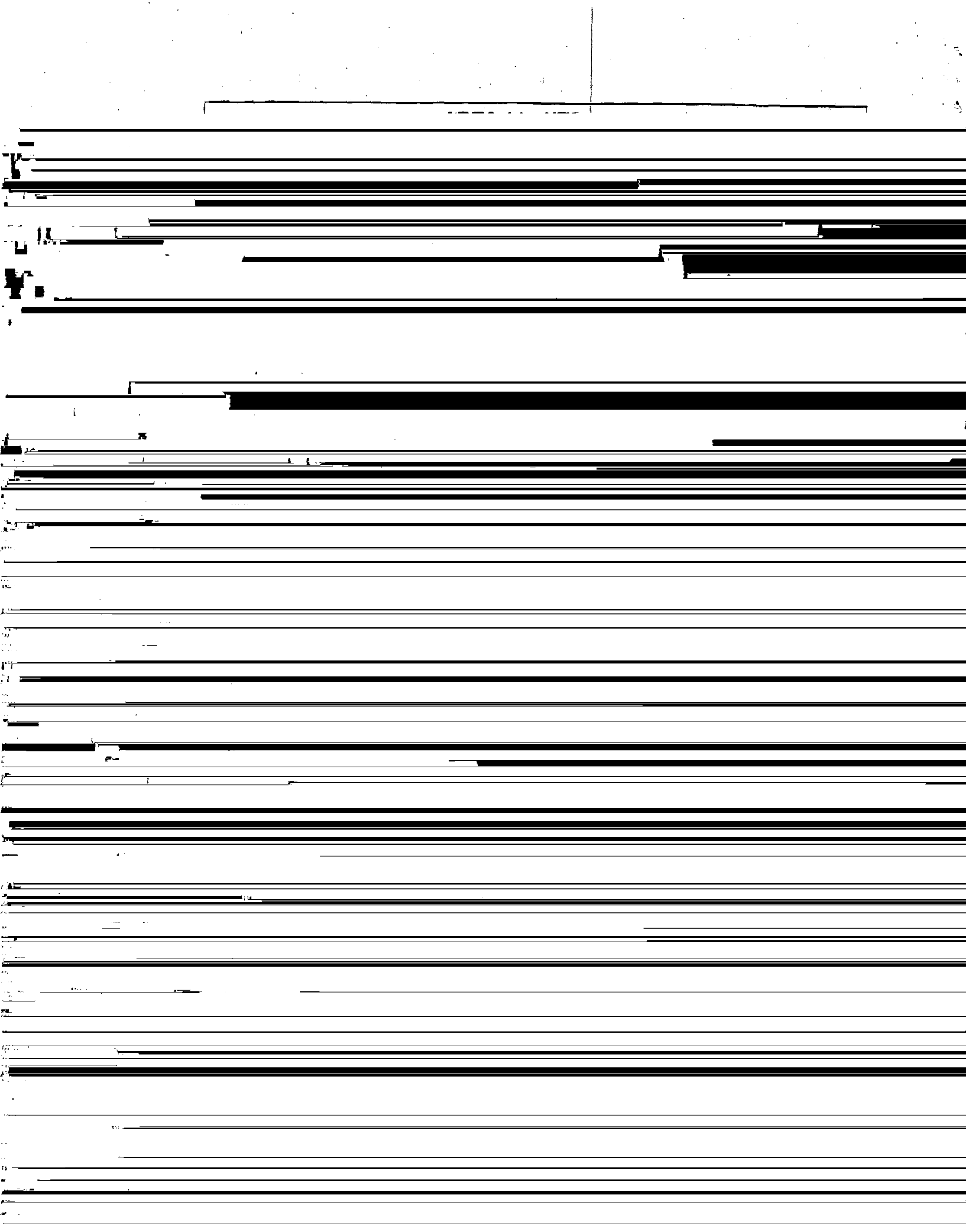


Figure 1. Location of safety test sites slated for plutonium decontamination at the Nevada Test Site (NTS), Tonopah Test Range (TTR), and the Nellis Air Force Range (NAFR).



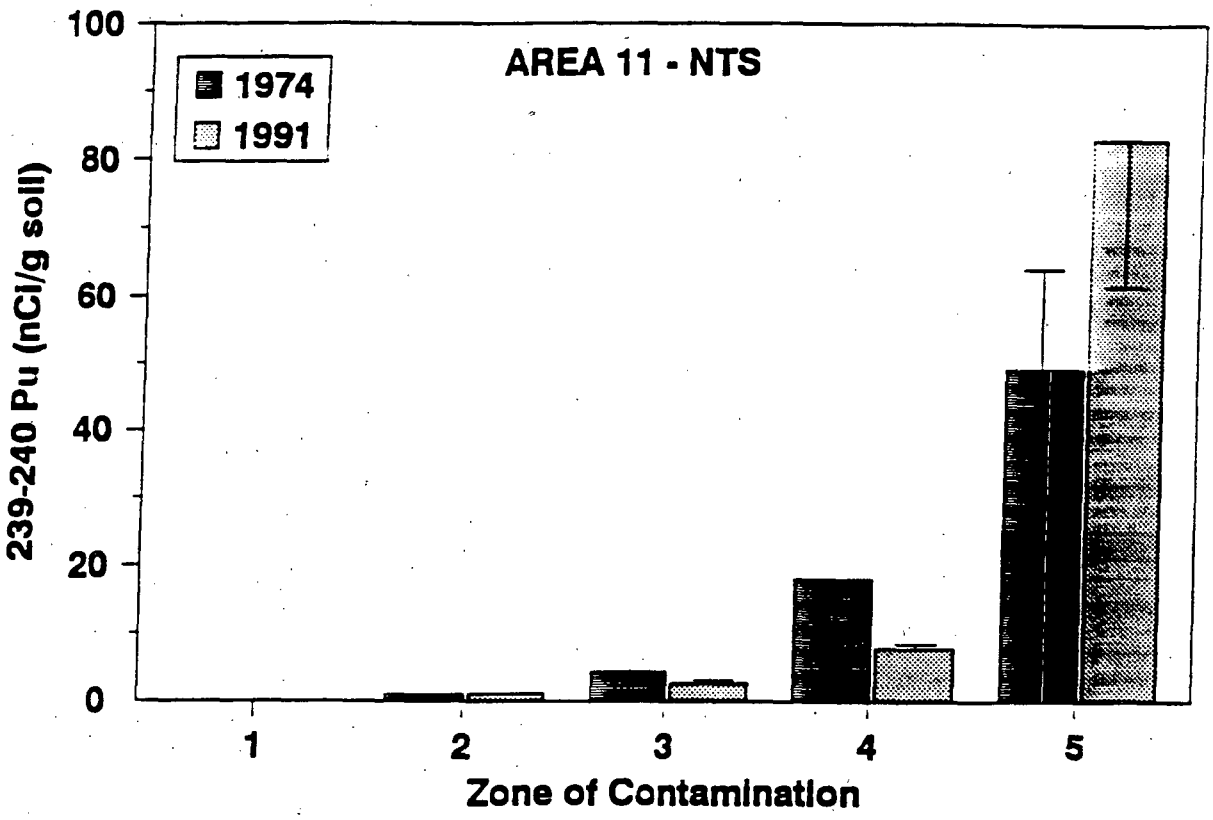
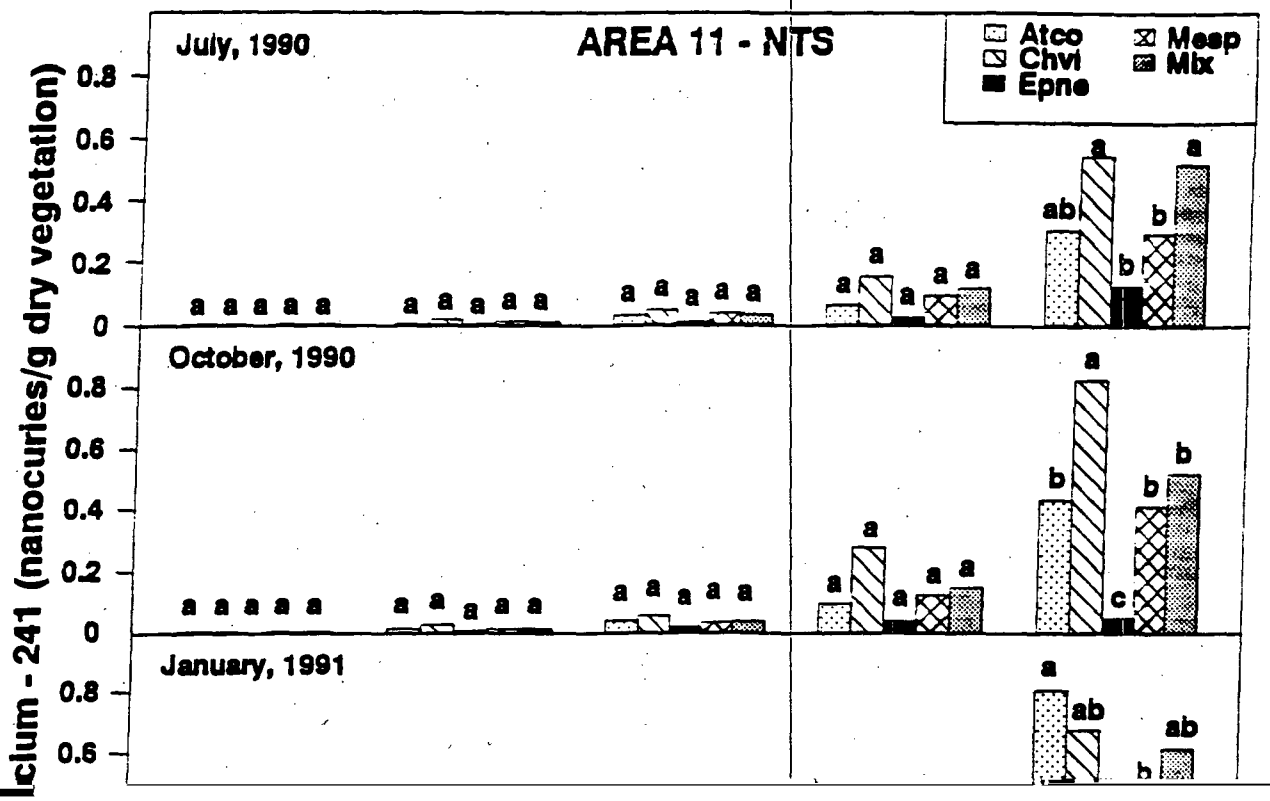


Figure 3. Past (1974) and present (1991) mean 239-240 plutonium (Pu) concentrations (nanocuries/g soil) in soils at Site D in Area 11 of the Nevada Test Site (NTS). Past means were derived from data in Gilbert et al. 1975. Lines on bars indicate standard errors for each mean.


AREA 11 - NTS
July, 1990
October, 1990
January, 1991
Atco
Chvi
Epne
Meap
Mix
lclum - 241 (nanocuries/g dry vegetation)
0.8
0.6
0.4
0.2
0

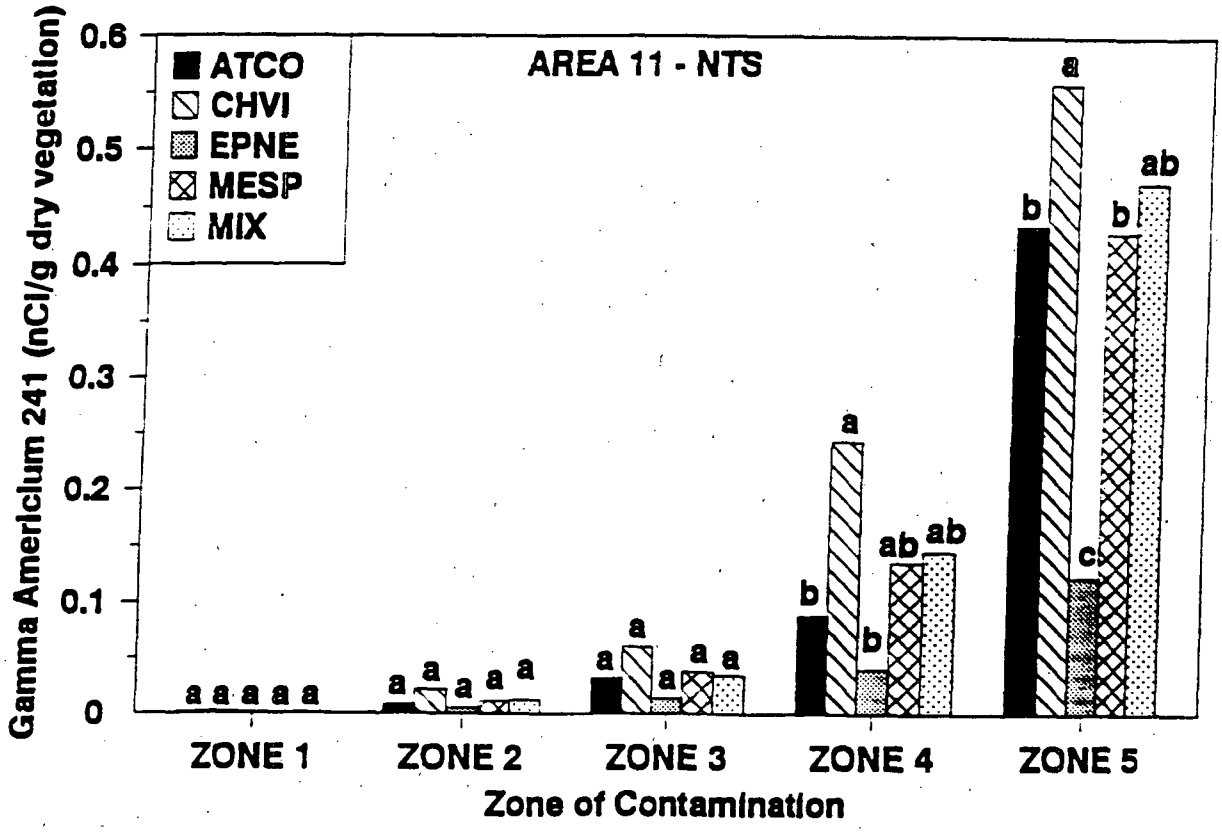


Figure 5. Gamma americium-241 means (n=12) (nanocuries/g dry vegetation) for *Atriplex confertifolia* (ATCO), *Chrysothamnus viscidiflorus* (CHVI), *Ephedra nevadensis* (EPNE), *Menodora spinescens* (MESP), and a mixture of perennial species (MIX) within zones of plutonium contamination averaged across four dates of collection in Area 11 (Site D) of the Nevada Test Site (NTS). Species means for each zone of contamination having the same letter are not significantly different ($p > 0.05$) using Fisher's Least Significant Difference (LSD) procedure.

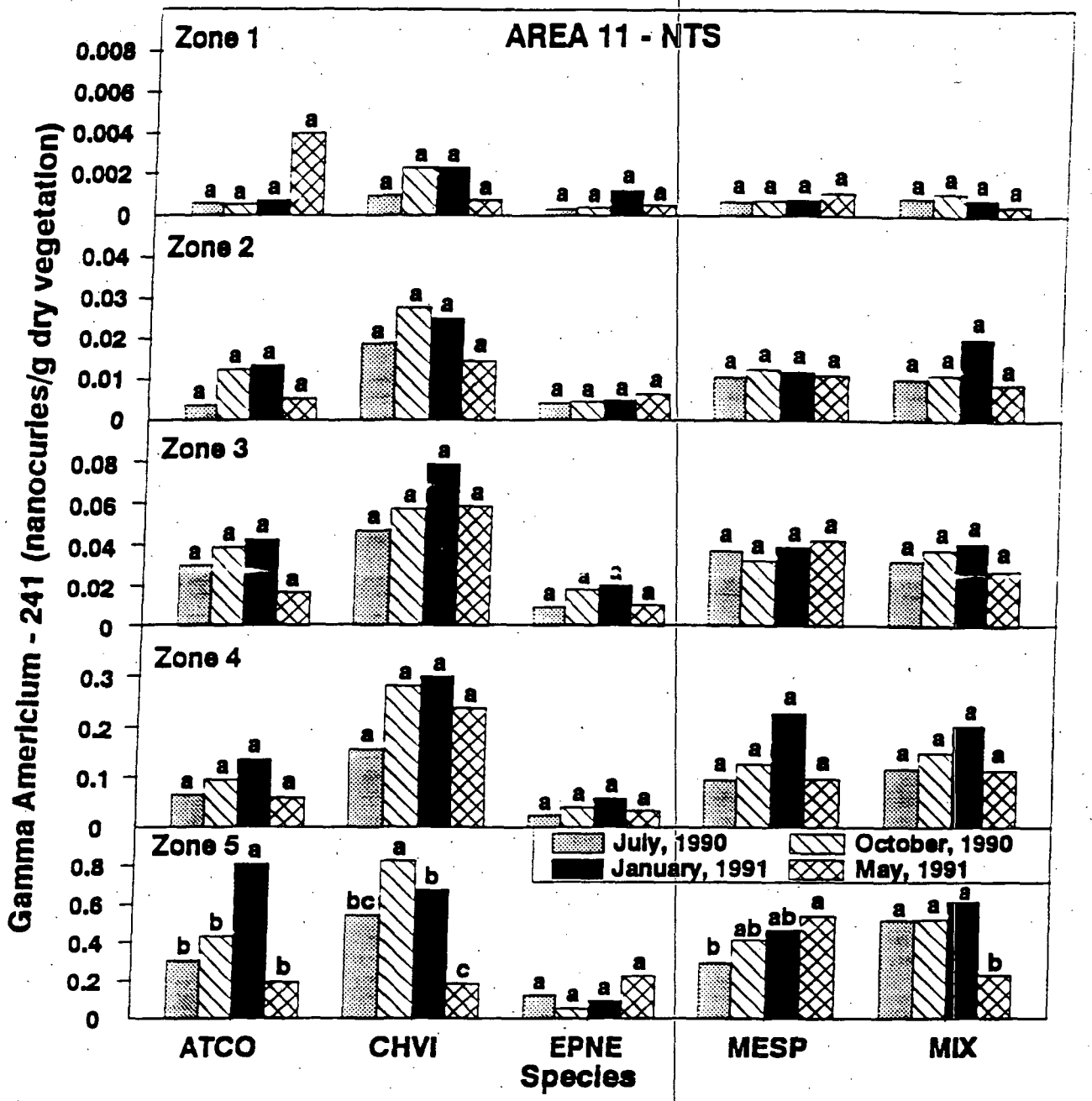


Figure 6. Gamma americium-241 means (n=3) (nanocuries/g dry vegetation) for *Atriplex confertifolia* (ATCO), *Chrysothamnus viscidiflorus* (CHVI), *Ephedra nevadensis* (EPNE), *Menodora spinescens* (MESP), and a mixture of perennial species (MIX) within zones of plutonium contamination on four dates of collection in Area 11 (Site D) of the Nevada Test Site (NTS) (Note differences in scale for each zone panel of the graph). Date of collection means for each zone of contamination and each species having the

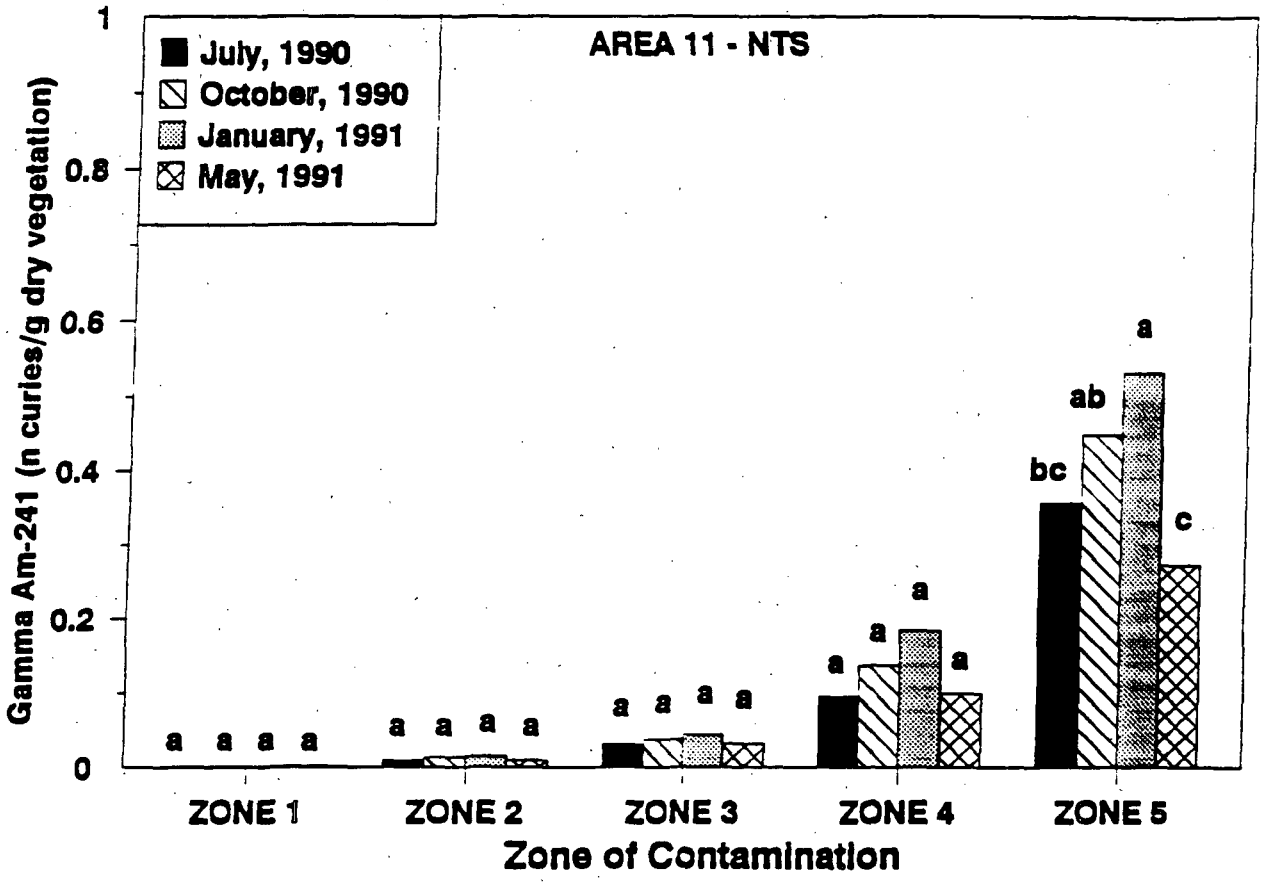


Figure 7. Gamma americium-241 means (n=15) (nanocuries/g dry vegetation) for dates of collection within zones of plutonium contamination averaged across all species sampled in Area 11 (Site D) of the Nevada Test Site (NTS). Date of collection means within each zone of contamination having the same letter are not significantly different ($p > 0.05$) using Fisher's Least Significant Difference (LSD) procedure. For numeric means and standard errors, refer to Table 5.

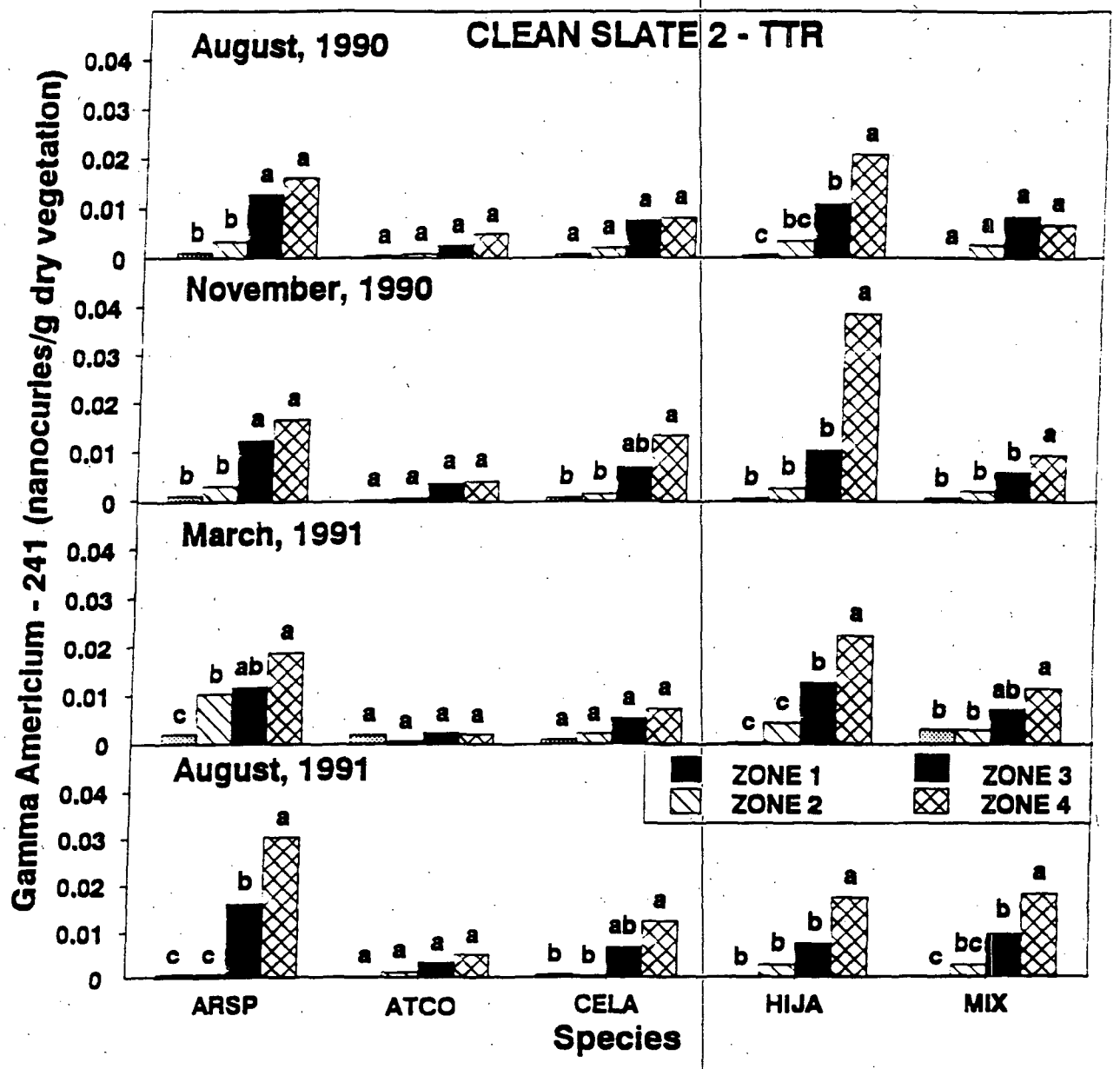


Figure 8. Gamma americium-241 means (n=3) (nanocuries/g dry vegetation) for *Artemisia spinescens* (ARSP), *Atriplex confertifolia* (ATCO), *Ceratoides lanata* (CELA), *Hilaria jamesii* (HIJA), and a mixture of perennial species (MIX) within zones of plutonium contamination collected on four separate dates at Clean Slate 2 of the Tonopah Test Range (TTR). Zone of contamination means for each species and date of collection having the same letter are not significantly different ($p > 0.05$) using Fisher's Least Significant Difference (LSD) procedure. For numeric means and standard errors, refer to Table 6.

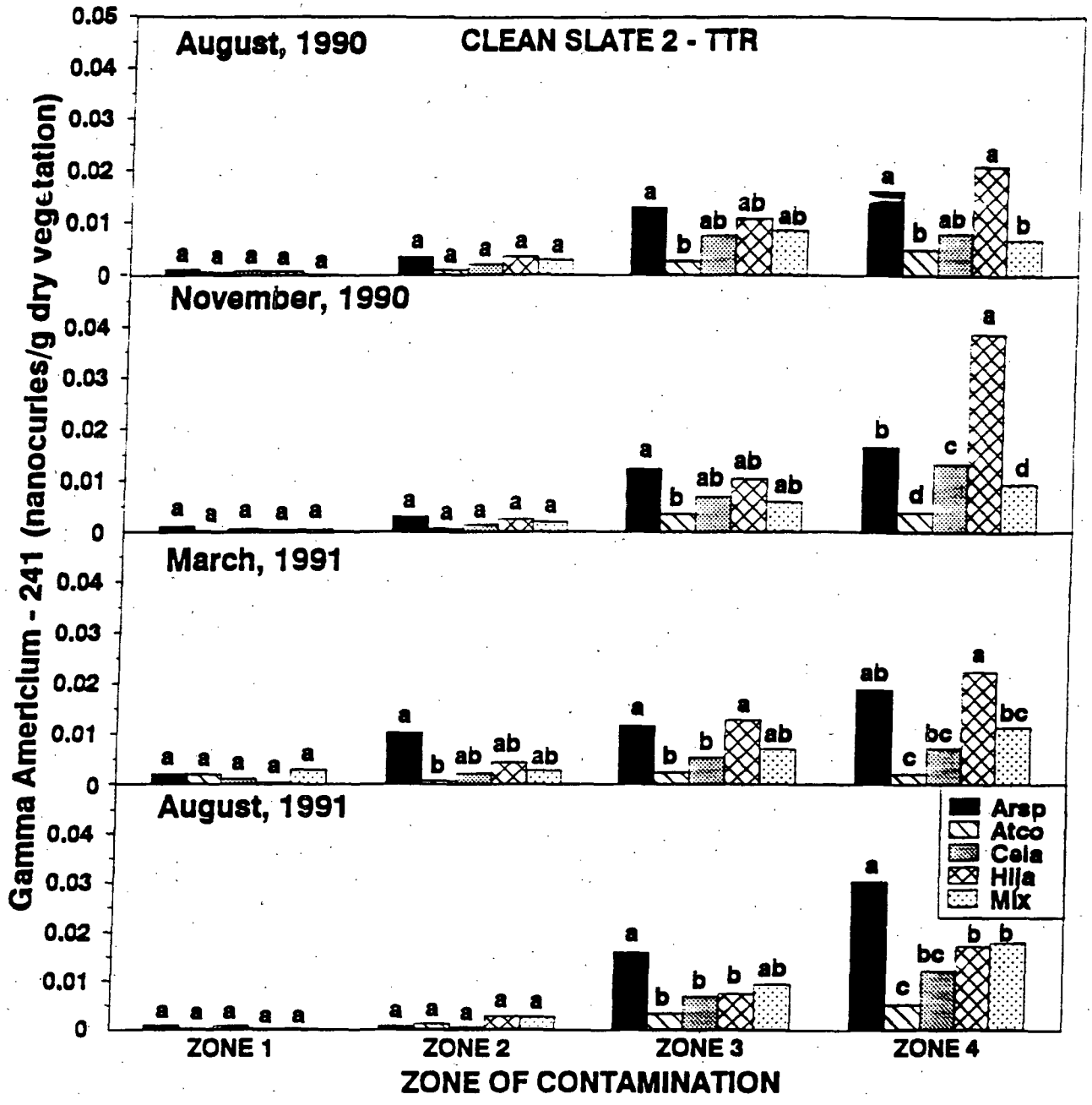


Figure 9. Gamma americium-241 means (n=3) (nanocuries/g dry vegetation) for *Artemisia spinescens* (ARSP), *Atriplex confertifolia* (ATCO), *Ceratoides lanata* (CELA), *Hilaria jamesii* (HIJA), and a mixture of perennial species (MIX) within zones of plutonium contamination collected on four separate dates at Clean Slate 2 of the Tonopah Test Range (TTR). Species means for each zone of contamination and sampling date having the same letter are not significantly different ($p > 0.05$) using Fisher's Least Significant Difference (LSD) procedure. For numeric means and standard errors, refer to Table 8.

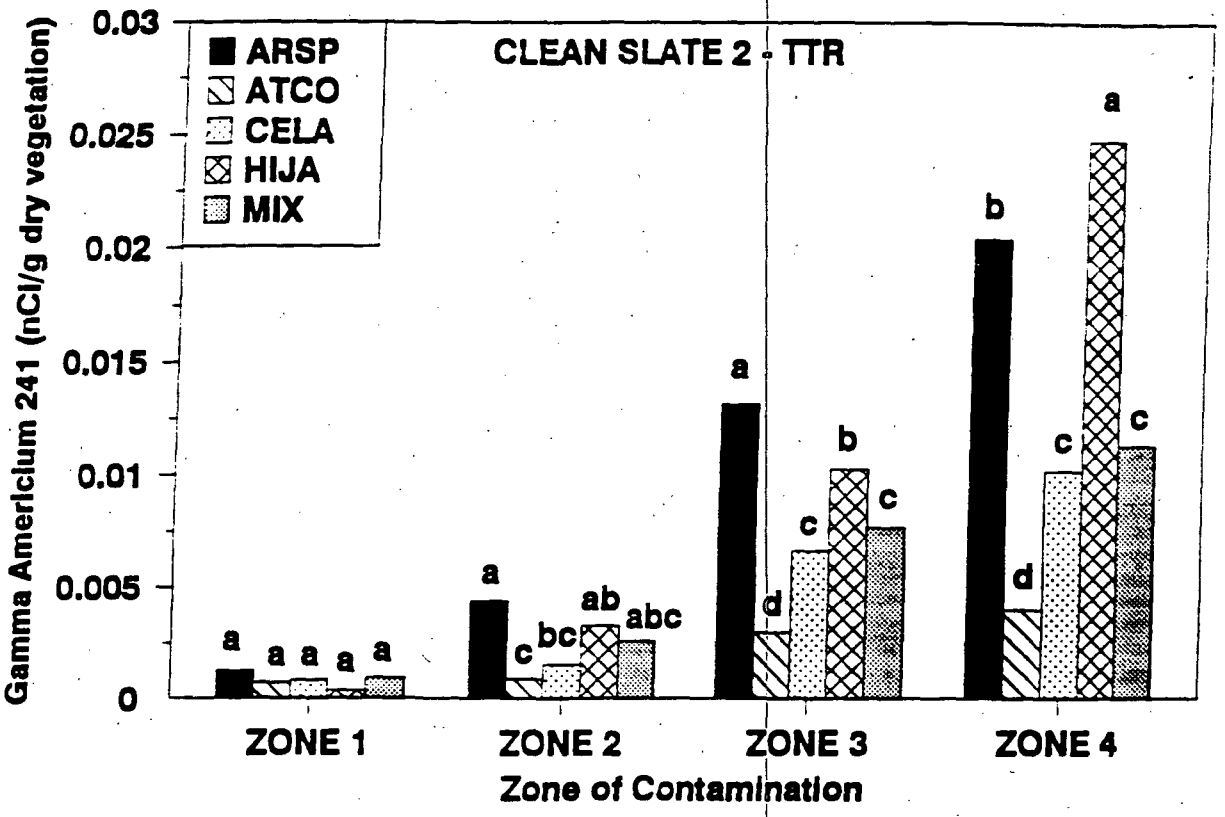
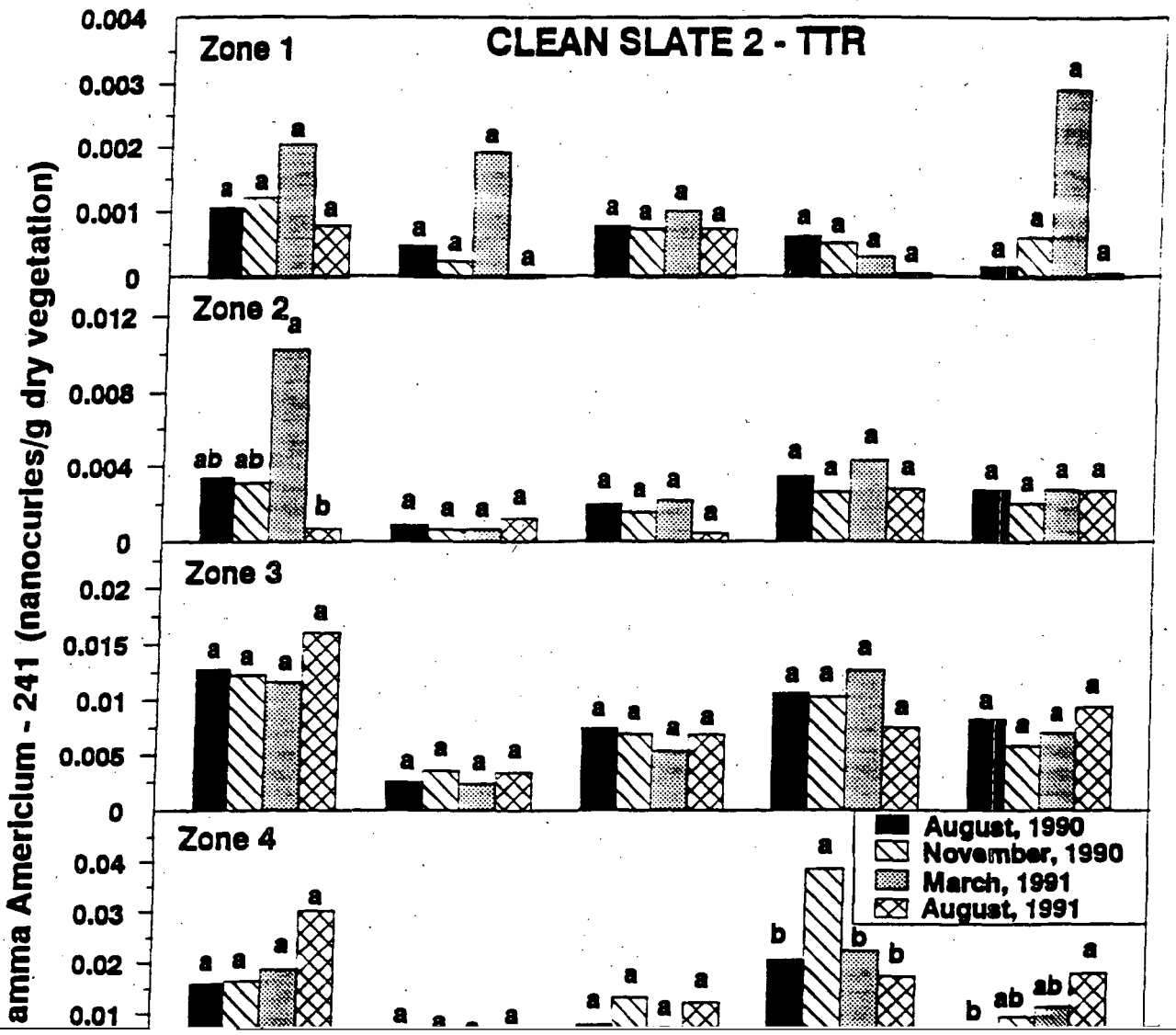


Figure 10. Gamma americium-241 means (n=12) (nanocuries/g dry vegetation) for *Artemisia spinescens* (ARSP), *Atriplex confertifolia* (ATCO), *Ceratoides lanata* (CELA), *Hilaria jamesii* (HIJA), and a mixture of perennial species (MIX) within zones of plutonium contamination averaged for all dates of vegetation collection at Clean Slate 2 of the Tonopah Test Range (TTR). Species means within each zone of contamination having the same letter are not significantly different ($p > 0.05$) using Fisher's Least Significant Difference (LSD) procedure.


CLEAN SLATE 2 - TTR
Zone 1
Zone 2a
Zone 3
Zone 4
amma Americium - 241 (nanocuries/g dry vegetation)
0.004
0.003
0.002
0.001
0
0.012
0.008
0.004
0
0.02
0.015
0.01
0.005
0
0.04
0.03
0.02
0.01
August, 1990
November, 1990
March, 1991
August, 1991

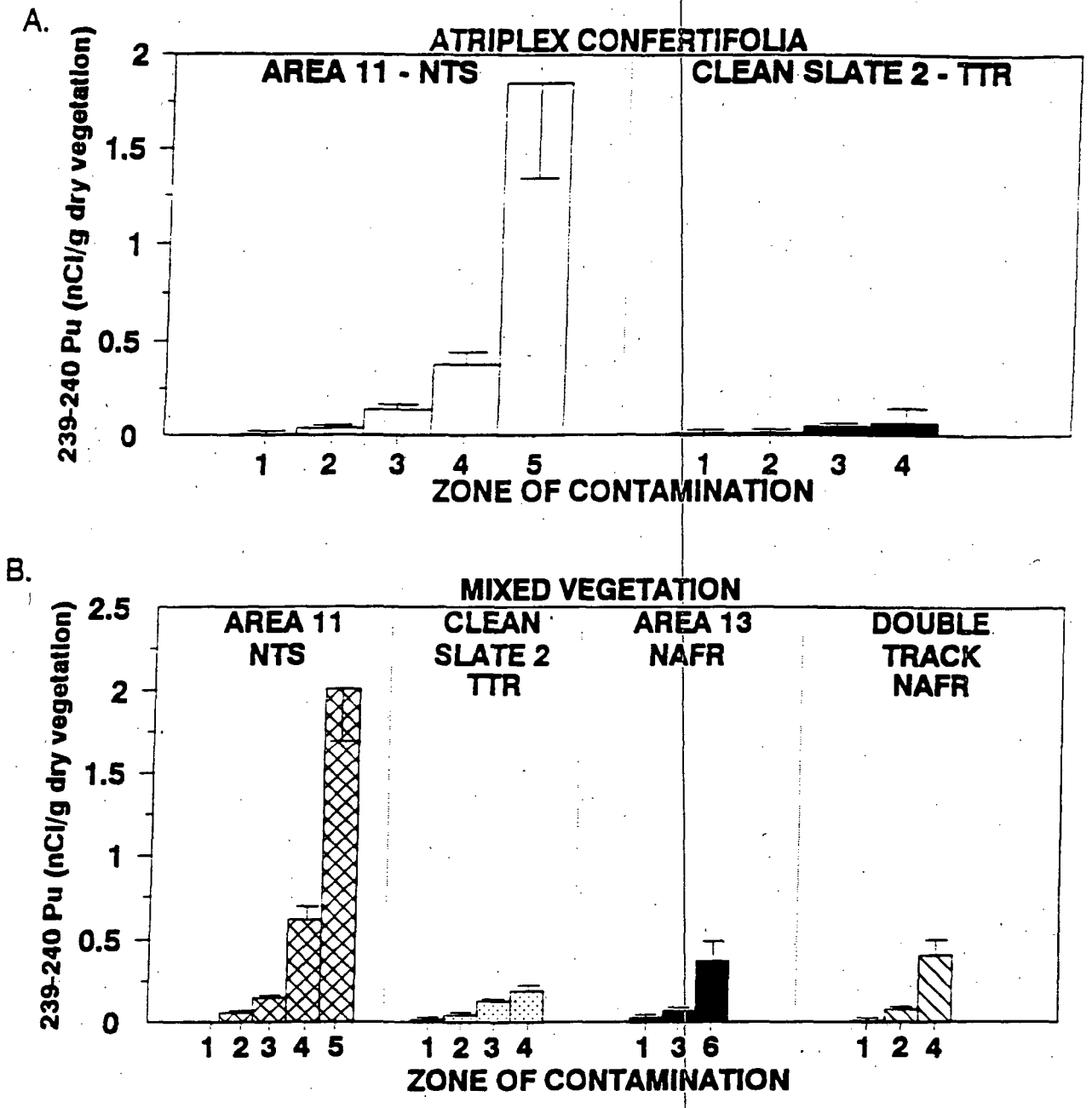
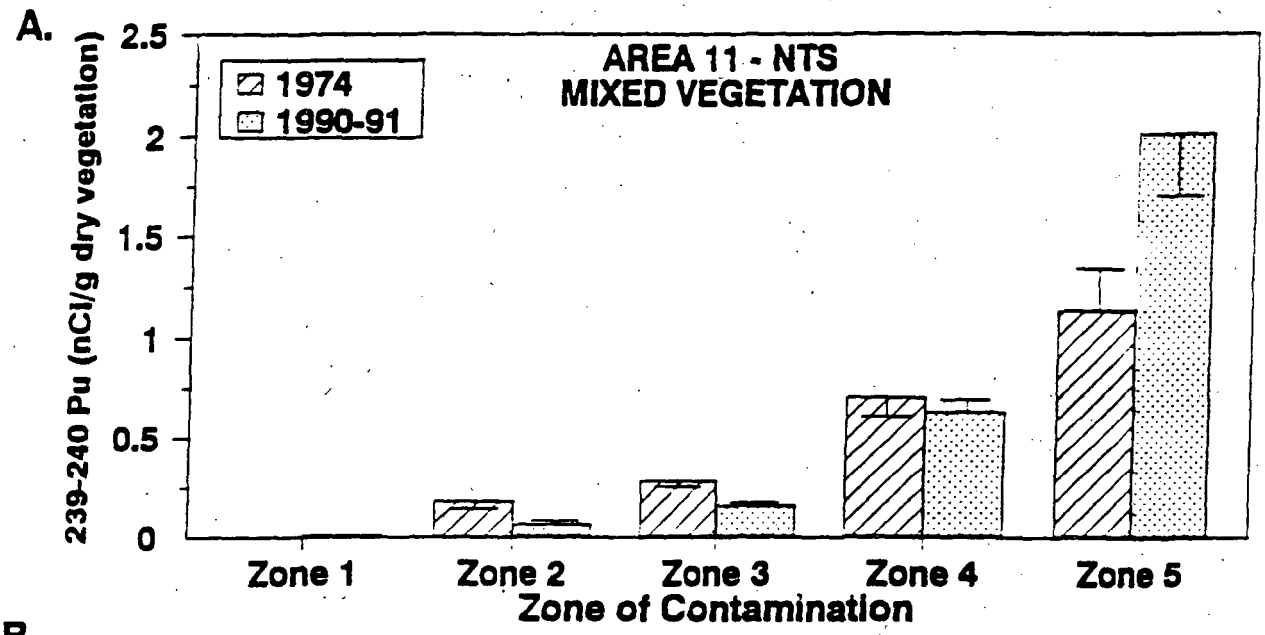
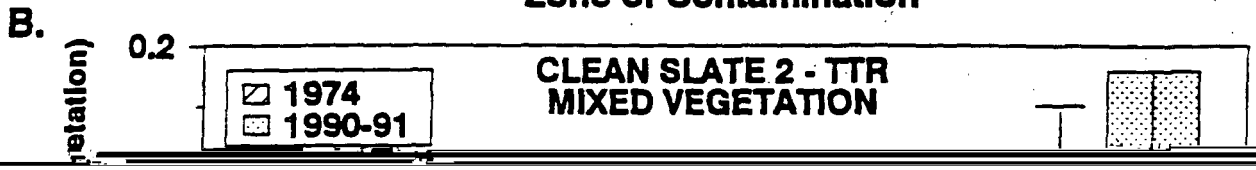


Figure 12. (A) Mean 239-240 Pu for *Atriplex confertifolia* at Site D in Area 11 of the Nevada Test Site (NTS) and Clean Slate 2 of the Tonopah Test Range (TTR). (B) Mean Pu 239-240 for mixed vegetation in Area 11 of the NTS, Clean Slate 2 of the TTR, and Area 13 and Double Track of the Nellis Air Force Range (NAFR). Lines within bars indicate standard errors of the mean.


A.
AREA 11 - NTS
MIXED VEGETATION
1974
1990-91
239-240 Pu (nCi/g dry vegetation)
2.5
2
1.5
1
0.5
0
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone of Contamination


B.
0.2
CLEAN SLATE 2 - TTR
MIXED VEGETATION
1974
1990-91

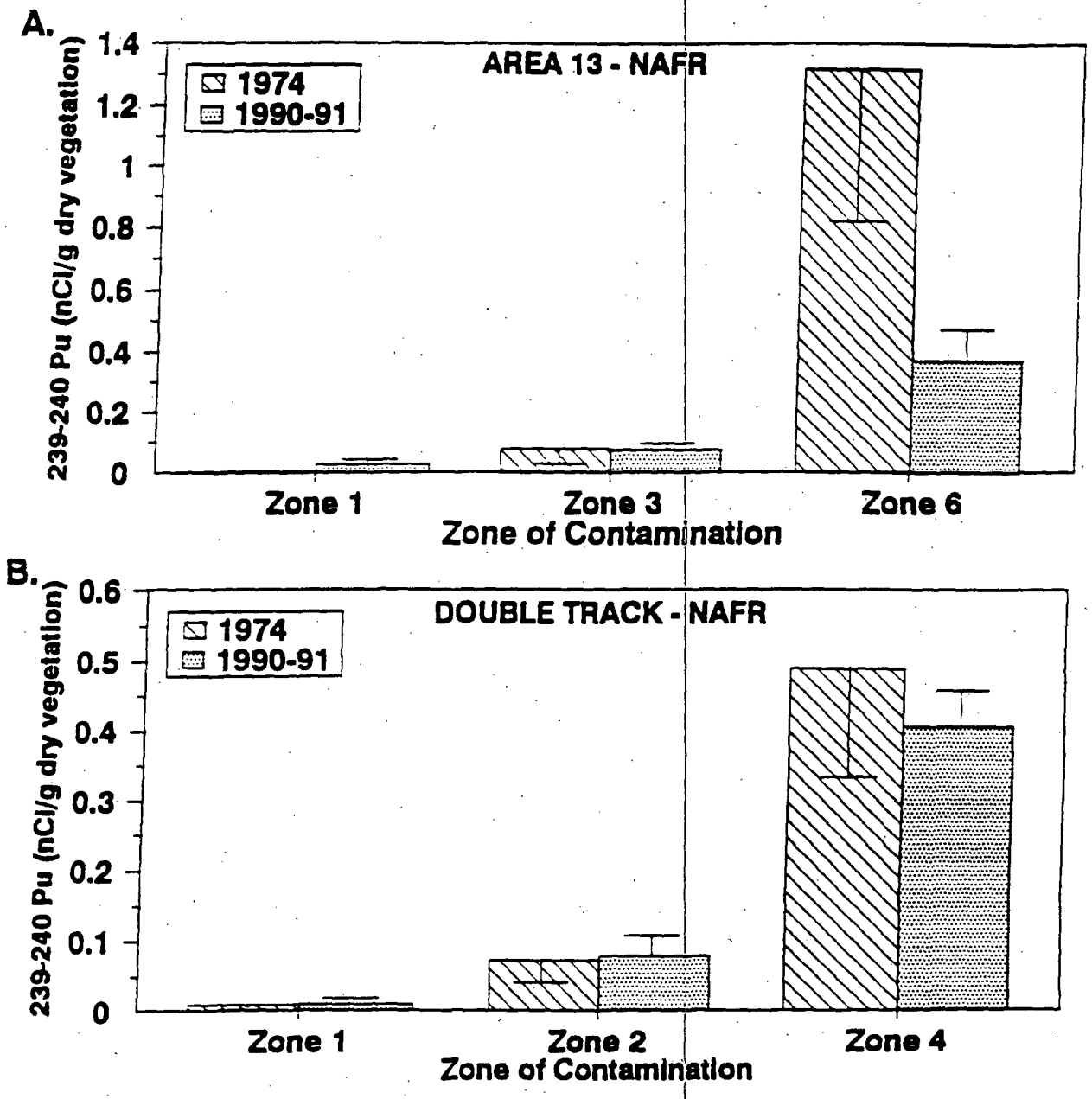


Figure 14. (A) Average past (1974) and present (1991) levels of 239-240 plutonium (Pu) (nanocuries/g dry vegetation) for mixed vegetation in Area 13 of the Nellis Air Force Range (NAFR). (B) Average past and present levels of 239-240 Pu for mixed vegetation at Double Track of the NAFR. Lines within bars for both graphs indicate standard errors of the mean. Means and standard errors were computed from individual species data from Romney et al. 1975.

Table 1. Gamma americium-241 means (n=3) and standard errors (SE) (nanocuries/g dry vegetation) for Atriplex confertifolia, Chrysothamnus viscidiflorus, Ephedra nevadensis, Menodora spinescens, and a mixture of perennial species within zones of plutonium contamination in Area 11 of the Nevada Test Site. Species were sampled on four separate dates representing different seasons. Mean separations were conducted using Fischer's Least Significant Difference procedure (LSD). Zone of contamination mean within the same species and date of collection having identical letters were not significantly different ($p>0.05$).

Zone of	Atriplex		Chrysothamnus		Ephedra		Menodora		Mixture of species	
Contamination	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
July, 1990										
Zone 1	0.00058	0.00006 b	0.00095	0.00001 b	0.00032	0.00032 a	0.00066	0.00006 b	0.00083	0.00004 b
Zone 2	0.00369	0.00086 b	0.01903	0.00531 b	0.00415	0.00074 a	0.01077	0.00060 b	0.01031	0.00060 b
Zone 3	0.02987	0.00065 b	0.04677	0.00009 b	0.00931	0.00140 a	0.03710	0.00674 b	0.03247	0.00402 b
Zone 4	0.06523	0.01839 ab	0.15470	0.05263 b	0.02519	0.02112 a	0.09457	0.00207 ab	0.11677	0.03847 b
Zone 5	0.30300	0.06258 a	0.54600	0.12905 a	0.12510	0.03906 a	0.29333	0.01985 a	0.52000	0.15459 a
October, 1990										
Zone 1	0.00053	0.00012 b	0.00232	0.00034 b	0.00040	0.00009 a	0.00071	0.00015 b	0.00109	0.00025 b
Zone 2	0.01247	0.00067 b	0.02787	0.00352 b	0.00462	0.00007 a	0.01263	0.00265 b	0.01145	0.00149 b
Zone 3	0.03883	0.00659 b	0.05710	0.00860 b	0.01787	0.00067 a	0.03223	0.00383 b	0.03760	0.00170 b

Table 2. Gamma americium-241 means (n=12) and standard errors (SE) (nanocuries/g dry vegetation) for Atriplex confertifolia (Atco), Chrysothamnus viscidiflorus (Chvi), Ephedra nevadensis (Epne), Menodora spinescens (Mesp), and a mixture of perennial species within zones of plutonium contamination in Area 11 of the Nevada Test Site. Means represent all dates of collection combined for each species and zone. Mean separations were conducted using Fischer's Least Significant Difference procedure (LSD). Means having identical letters within species columns were not significantly different ($p>0.05$).

Zone of	Atriplex		Chrysothamnus		Ephedra		Menodora		Mixture of species	
Contamination	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Zone 1	0.00146	0.00089 b	0.00159	0.00032 c	0.00060	0.00016 c	0.00080	0.00015 c	0.00080	0.00009 c
Zone 2	0.00878	0.00150 b	0.02169	0.00218 c	0.00510	0.00042 c	0.01169	0.00094 c	0.01279	0.00173 c
Zone 3	0.03196	0.00371 b	0.06023	0.00465 c	0.01439	0.00186 bc	0.03762	0.00249 bc	0.03462	0.00207 c
Zone 4	0.08845	0.01474 b	0.24311	0.04633 b	0.04033	0.00695 ab	0.13593	0.02516 b	0.14553	0.01545 b
Zone 5	0.43458	0.11852 a	0.55875	0.12134 a	0.12342	0.02218 a	0.42923	0.05840 a	0.47150	0.07178 a

Table 3. Gamma americium-241 means (n=3) and standard errors (SE) (nanocuries/g dry vegetation) for Atriplex confertifolia (Atco), Chrysothamnus viscidiflorus (Chvi), Ephedra nevadensis (Epne), Menodora spinescens (Mesp), and a mixture of perennial species within zones of plutonium contamination in Area 11 of the Nevada Test Site. Vegetation was collected on four separate dates representing different seasons. Mean separations were conducted using Fischer's Least Significant Difference procedure (LSD). Species means within the same sampling date and zone of contamination having identical letters were not significantly different ($p>0.05$).

	Zone 1		Zone 2		Zone 3		Zone 4		Zone 5	
Species	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
July, 1990										
Atco	0.00058	0.00006 a	0.00369	0.00086 a	0.02987	0.00065 a	0.06523	0.01839 a	0.30300	0.06258 ab
Chvi	0.00095	0.00001 a	0.01903	0.00531 a	0.04677	0.00009 a	0.15470	0.05263 a	0.54600	0.12905 a
Epne	0.00032	0.00032 a	0.00415	0.00074 a	0.00931	0.00140 a	0.02519	0.02112 a	0.12510	0.03906 b
Mesp	0.00066	0.00006 a	0.01077	0.00060 a	0.03710	0.00674 a	0.09457	0.00207 a	0.29333	0.01985 b
Mixture	0.00083	0.00004 a	0.01031	0.00060 a	0.03247	0.00402 a	0.11677	0.03847 a	0.52000	0.15459 a
October, 1990										
Atco	0.00053	0.00012 a	0.01247	0.00067 a	0.03883	0.00659 a	0.09394	0.04466 a	0.43267	0.16303 b
Chvi	0.00232	0.00034 a	0.02787	0.00352 a	0.05710	0.00860 a	0.27970	0.16902 a	0.82767	0.42935 a
Epne	0.00040	0.00009 a	0.00462	0.00007 a	0.01787	0.00067 a	0.03980	0.01016 a	0.05107	0.01817 c
Mesp	0.00071	0.00015 a	0.01263	0.00265 a	0.03223	0.00383 a	0.12500	0.02650 a	0.41190	0.22411 b
Mixture	0.00109	0.00025 a	0.01145	0.00149 a	0.03760	0.00170 a	0.14833	0.01225 a	0.52167	0.12454 b
January 1991										

Table 4. Gamma americium -241 means (n=3) and standard errors (nanocuries/g dry vegetation) for different seasons of collection for Atriplex confertifolia, Chrysothamnus viscidiflorus, Ephedra nevadensis, Menodora spinescens, and a mixture of perennial species within zones of plutonium contamination in Area 11 of the Nevada Test Site. Mean separations were conducted using Fischer's Least Significant Difference procedure (LSD). Date of collection means within the same species and zone having identical letters were not significantly different (p>0.05).

	Zone 1		Zone 2		Zone 3		Zone 4		Zone 5	
Date of collection	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Atriplex confertifolia										
July, 1990	0.00058	0.00006 a	0.00369	0.00086 a	0.02987	0.00065 a	0.06523	0.01839 a	0.30300	0.06258 b
October, 1990	0.00053	0.00012 a	0.01247	0.00067 a	0.03883	0.00659 a	0.09394	0.04466 a	0.43267	0.16303 b
January, 1991	0.00071	0.00004 a	0.01355	0.00334 a	0.04247	0.00737 a	0.13507	0.02221 a	0.81033	0.40777 a
May, 1991	0.00402	0.00359 a	0.00543	0.00077 a	0.01667	0.00264 a	0.05957	0.01288 a	0.19233	0.06047 b
Chrysothamnus viscidiflorus										
July, 1990	0.00095	0.00001 a	0.01903	0.00531 a	0.04677	0.00009 a	0.15470	0.05263 a	0.54600	0.12905 b
October, 1990	0.00232	0.00034 a	0.02787	0.00352 a	0.05710	0.00860 a	0.27970	0.16902 a	0.82767	0.42935 a
January, 1991	0.00234	0.00101 a	0.02520	0.00301 a	0.07870	0.00885 a	0.29900	0.04293 a	0.67733	0.09416 ab
May, 1991	0.00074	0.00014 a	0.01467	0.00100 a	0.05837	0.00742 a	0.23700	0.00900 a	0.18400	0.02371 c

Table 5. Gamma americium-241 means (n=15) and standard errors (SE) (nanocuries/g dry vegetation) within zones of plutonium contamination in Area 11 of the Nevada Test Site on four separate dates of vegetation collection representing different seasons. Mean separations were conducted using Fischer's Least Significant Difference procedure (LSD). Date of collection means within the same zone of contamination having identical letters were not significantly different ($p>0.05$).

Date of collection	Zone 1		Zone 2		Zone 3		Zone 4		Zone 5	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
July, 1990	0.00067	0.00008 a	0.00959	0.00176 a	0.03110	0.00356 a	0.09601	0.01706 a	0.35749	0.05553 bc
October, 1990	0.00101	0.00020 a	0.01381	0.00219 a	0.03673	0.00390 a	0.13735	0.03683 a	0.44899	0.11101 ab
January, 1991	0.00116	0.00025 a	0.01526	0.00210 a	0.04422	0.00560 a	0.18445	0.02768 a	0.53297	0.10184 a
May, 1991	0.00136	0.00071 a	0.00939	0.00121 a	0.03101	0.00498 a	0.09896	0.01885 a	0.27453	0.03913 c

Table 7. Gamma americium-241 means (n=12) and standard errors (SE) (nanocuries/g dry vegetation) for Artemisia spinescens, Atriplex confertifolia, Ceratoides lanata, Hilaria jamesii, and a mixture of perennial species in zones of plutonium contamination within the Clean Slate 2 safety shot site at the Tonopah Test Range, Nevada. Mean separations were conducted using Fischer's Least Significant Difference procedure (LSD). Zone of contamination means within the same species column having identical letters were not significantly different (p>0.05).

Zone of Contamination	Artemisia		Atriplex		Ceratoides		Hilaria		Mixture of species	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Zone 1	0.00128	0.00017 c	0.00069	0.00049 a	0.00081	0.00010 b	0.00037	0.00010 c	0.00094	0.00065 c
Zone 2	0.00439	0.00167 c	0.00088	0.00011 a	0.00154	0.00026 b	0.00329	0.00036 c	0.00259	0.00021 c
Zone 3	0.01318	0.00077 b	0.00298	0.00032 a	0.00664	0.00052 a	0.01028	0.00095 b	0.00768	0.00064 b
Zone 4	0.02040	0.00267 a	0.00399	0.00046 a	0.01019	0.00122 a	0.02476	0.00441 a	0.01133	0.00209 a

Table 8. Gamma americium-241 means (n=3) and standard errors (SE) (nanocuries/g dry vegetation) for Artemisia spinescens (Arsp), Atriplex confertifolia (Atco), Ceratoides lanata (Cela), Hilaria jamesii (Hija), and a mixture of perennial species within zones of plutonium contamination within the Clean Slate 2 safety shot site at the Tonopah Test Range, Nevada. Vegetation was collected on four separate dates to represent seasons. Mean separations were conducted using Fischer's Least Significant Difference procedure (LSD). Species means within the same date of collection and zone of contamination having identical letters were not significantly different ($p>0.05$).

	ZONE 1		ZONE 2		ZONE 3		ZONE 4	
Species	Mean	SE	Mean	SE	Mean	SE	Mean	SE
August, 1990								
Arsp	0.00107	0.00020 a	0.00341	0.00024 a	0.01277	0.00137 a	0.01597	0.00757 a
Atco	0.00048	0.00020 a	0.00092	0.00034 a	0.00255	0.00040 b	0.00485	0.00086 b
Cela	0.00078	0.00015 a	0.00198	0.00051 a	0.00747	0.00109 ab	0.00796	0.00180 ab
Hija	0.00062	0.00014 a	0.00346	0.00078 a	0.01064	0.00171 ab	0.02077	0.00306 a
Mixture	0.00017	0.00017 a	0.00276	0.00039 a	0.00833	0.00024 ab	0.00663	0.00135 a
November, 1990								
Arsp	0.00121	0.00016 a	0.00314	0.00088 a	0.01222	0.00129 a	0.01653	0.00223 b
Atco	0.00025	0.00013 a	0.00067	0.00009 a	0.00358	0.00106 b	0.00394	0.00048 d
Cela	0.00073	0.00017 a	0.00154	0.00009 a	0.00690	0.00132 ab	0.01331	0.00369 c
Hija	0.00051	0.00003 a	0.00258	0.00022 a	0.01027	0.00133 ab	0.03860	0.01650 a
Mixture	0.00061	0.00005 a	0.00207	0.00029 a	0.00589	0.00078 ab	0.00940	0.00051 d
March, 1991								
Arsp	0.00205	0.00024 a	0.01029	0.00596 a	0.01167	0.00066 a	0.01883	0.00123 ab
Atco	0.00193	0.00182 a	0.00068	0.00007 b	0.00237	0.00023 b	0.00202	0.00060 d
Cela	0.00101	0.00008 a	0.00218	0.00051 ab	0.00538	0.00054 b	0.00724	0.00090 cd
Hija	0.00031	0.00031 a	0.00435	0.00077 ab	0.01267	0.00207 a	0.02237	0.00282 a
Mixture	0.00292	0.00254 a	0.00280	0.00062 ab	0.00704	0.00130 ab	0.01132	0.00385 bc
August, 1991								
Arsp	0.00079	0.00026 a	0.00072	0.00011 a	0.01607	0.00179 a	0.03027	0.00508 a
Atco	0.00004	0.00001 a	0.00124	0.00012 a	0.00343	0.00057 b	0.00517	0.00050 c
Cela	0.00073	0.00037 a	0.00044	0.00014 a	0.00682	0.00125 b	0.01223	0.00112 bc
Hija	0.00006	0.00003 a	0.00277	0.00083 a	0.00753	0.00207 b	0.01730	0.00217 b
Mixture	0.00007	0.00001 a	0.00271	0.00046 a	0.00946	0.00173 ab	0.01795	0.00664 b

Table 9. Gamma americium-241 means (n=3) and standard errors (nanocuries/g dry vegetation) for different seasons of collection for

Artemisia spinescens, Atriplex confertifolia, Ceratoides lanata, Hilaria jamesii, and a mixture of perennial species within zones of plutonium contamination within the Clean Slate 2 safety shot site at the Tonopah Test Range, Nevada. Mean separations were conducted using Fischer's Least Significant Difference procedure (LSD). Date of collection means within the same species and zone having the same letter were not significantly different ($p>0.05$).

	ZONE 1		ZONE 2		ZONE 3		ZONE 4	
Date of collection	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Artemisia spinescens								
August, 1990	0.00107	0.00020 a	0.00341	0.00024 ab	0.01277	0.00137 a	0.01597	0.00757 b
November, 1990	0.00121	0.00016 a	0.00314	0.00088 ab	0.01222	0.00129 a	0.01653	0.00223 b
March, 1991	0.00205	0.00024 a	0.01029	0.00596 a	0.01167	0.00066 a	0.01883	0.00123 b
August, 1991	0.00079	0.00026 a	0.00072	0.00011 b	0.01607	0.00179 a	0.03027	0.00508 a
Atriplex confertifolia								
August, 1990	0.00048	0.00020 a	0.00092	0.00034 a	0.00255	0.00040 a	0.00485	0.00086 a
November, 1990	0.00025	0.00013 a	0.00067	0.00009 a	0.00358	0.00106 a	0.00394	0.00048 a
March, 1991	0.00193	0.00182 a	0.00068	0.00007 a	0.00237	0.00023 a	0.00202	0.00060 a
August, 1991	0.00004	0.00001 a	0.00124	0.00012 a	0.00343	0.00057 a	0.00517	0.00050 a
Ceratoides lanata								
August, 1990	0.00078	0.00015 a	0.00198	0.00051 a	0.00747	0.00109 a	0.00796	0.00180 a
November, 1990	0.00073	0.00017 a	0.00154	0.00009 a	0.00690	0.00132 a	0.01331	0.00369 a
March, 1991	0.00101	0.00008 a	0.00218	0.00051 a	0.00538	0.00054 a	0.00724	0.00090 a
August, 1991	0.00073	0.00037 a	0.00044	0.00014 a	0.00682	0.00125 a	0.01223	0.00112 a
Hilaria jamesii								
August, 1990	0.00062	0.00014 a	0.00346	0.00078 a	0.01064	0.00171 a	0.02077	0.00306 b
November, 1990	0.00051	0.00003 a	0.00258	0.00022 a	0.01027	0.00133 a	0.03860	0.01650 a
March, 1991	0.00031	0.00031 a	0.00435	0.00077 a	0.01267	0.00207 a	0.02237	0.00282 b
August, 1991	0.00006	0.00003 a	0.00277	0.00083 a	0.00753	0.00207 a	0.01730	0.00217 b
Mixture of species								
August, 1990	0.00017	0.00017 a	0.00276	0.00039 a	0.00833	0.00024 a	0.00663	0.00135 b
November, 1990	0.00061	0.00005 a	0.00207	0.00029 a	0.00589	0.00078 a	0.00940	0.00051 ab
March, 1991	0.00292	0.00254 a	0.00280	0.00062 a	0.00704	0.00130 a	0.01132	0.00385 ab
August, 1991	0.00007	0.00001 a	0.00271	0.00046 a	0.00946	0.00173 a	0.01795	0.00664 a

Table 10. Gamma americium-241 means (n=15) and standard errors (SE) (nanocuries/g dry vegetation) for vegetation in zones of plutonium contamination within the Clean Slate 2 safety shot site at the Tonopah Test Range, Nevada. Vegetation was collected on four separate dates to represent seasons. Mean separations were conducted using Fischer's Least Significant Difference procedure (LSD). Date of collection means within zones of contamination having identical letters were not significantly different ($p>0.05$).

Date of Collection	Zone 1		Zone 2		Zone 3		Zone 4	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
August, 1990	0.00063	0.00011 a	0.00251	0.00032 a	0.00835	0.00101 a	0.01124	0.00217 b
November, 1990	0.00066	0.00010 a	0.00200	0.00028 a	0.00777	0.00094 a	0.01636	0.00429 a
March, 1991	0.00165	0.00059 a	0.00406	0.00136 a	0.00782	0.00112 a	0.01236	0.00216 b
August, 1991	0.00034	0.00012 a	0.00158	0.00031 a	0.00866	0.00127 a	0.01658	0.00265 a